Combining satellite lidar, airborne lidar, and ground plots to estimate the amount and distribution of aboveground biomass in the boreal forest of North America

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Objectives:

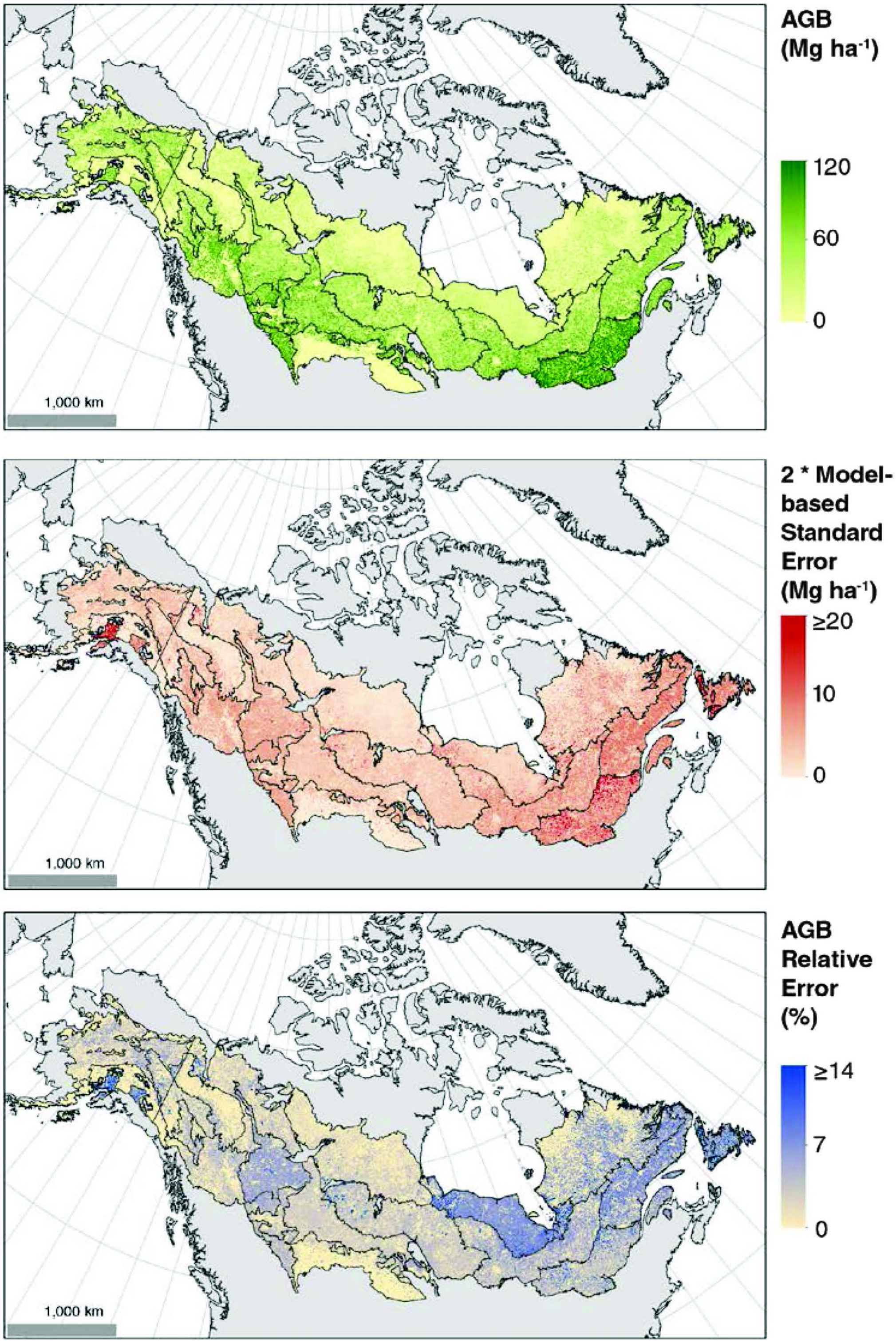
- This paper reports estimates of the amount, distribution and uncertainty of aboveground biomass (AGB) of the different ecoregions and forest land cover classes within the North American boreal forest.
- The authors also analyzed the factors driving the error estimates and compared the study estimates with other available North American estimates.
- A three-phase sampling strategy was used to tie ground plot AGB to airborne profiling lidar metrics and to link the airborne estimates of AGB to ICESat-GLAS lidar measurements such that GLAS could be used as a regional sampling tool.
- The three-phase sampling strategy involves: 1) building an initial statistical model to link Portable Airborne Laser System (PALS) height measurement to ground plot biomass; 2) building a second model to related the estimated biomass from the airborne lidar to the height metrics obtained by GLAS for the 1325 GLAS pulses that were flown by the aircraft; and 3) using the GLAS height metrics, slope, and land cover for quality-filtered GLAS pulses available to calculate the AGB and carbon stocks by land cover type.
- The uncertainties of the AGB estimates were calculated using a variance estimator that accounted for sampling error (i.e., the variability among GLAS orbital estimates) and the airborne-to-spaceborne regression error (i.e. the uncertainty of the model coefficients).

New Science:

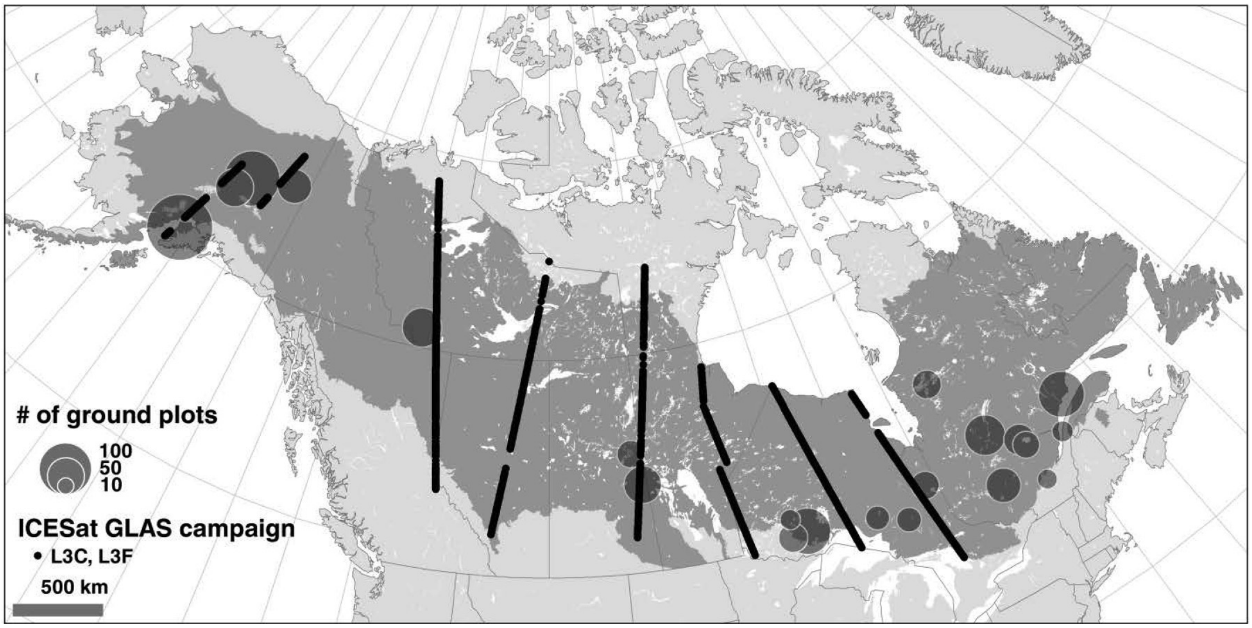
- The authors estimated the AGB of the North American boreal forest at 21.8 Pg with a relative error of 1.9% based on 256 GLAS orbits (299,086 pulses).
- The distribution of AGB was 46.6% for western Canada, 43.7% for eastern Canada and 9.7% for Alaska.
- Relative errors were generally under 4% for the three regions and for the major cover types in these regions and under 10% for ecoregions.
- The exception to this was for recently burned areas, which showed 9.3% relative error, likely due to the insensitivity of GLAS in short vegetation.
- AGB densities derived from GLAS agreed closely with the estimates derived from both forest inventories (<16%) and a MODIS-based interpolation technique (<26%) for more southern, well-inventoried ecoregions, whereas differences were much greater for unmanaged northern and (or) mountainous ecoregions.
- Because GLAS is a north-south near-polar orbiter, small ecoregions that are limited in their east-west extent have fewer GLAS orbits, greater sampling error and usually a lower percent modeling error; this includes Yukon Interior Dry Forests, Copper Plateau Taiga and Cook Inlet Taiga.
- Modeling error tends to be stable regardless of the size of the area of interest and is not impacted by differences in sampling intensity.

Significance:

- The North American boreal forest is vast, encompassing about 3.7 million square kilometers, of which 58% is classified as forest and other wooded land, and it provides critical ecosystem services at local, regional and global scales, including the storage of large amounts of carbon in living biomass and in soils.
- The amount of carbon sequestered in the boreal forest and soils is vulnerable to climate change, which has the potential to create positive feedbacks through which decreases in carbon sequestration lead to increased atmospheric CO_2 concentrations, further exacerbating climate warming.
- Because of the importance of the boreal forest in carbon sequestration and climate, it is useful to examine different approaches for monitoring boreal carbon and to explore the development of new monitoring capabilities.
- Laser-ranging airborne lidar has the potential to provide supplemental information on AGB density of forests and is particularly useful in extending AGB measurements into areas where few, if any, ground plots exist, such as unmanaged forest regions.
- Although GLAS stopped obtaining data for forest applications in 2006, this study still provides a useful proof-of-concept of how a spaceborne lidar can be combined with ground plots and airborne measurements to conduct large-scale AGB assessments at the biome scale for both the density and the total AGB.
- There are sources of error that were not explicitly included in the current analysis which should be addressed in future work if statistical theory advances to the point where this become tractable; these include errors due to the allometric models, uncertainty in model parameters for regressions between ground plots and airborne lidar metrics, geolocation-field measurement errors, land cover misclassification and artifacts in the Digital Elevation Model (DEM).
- The approach described here provides a framework for making repeated, periodic, satellite-based forest inventories to monitor boreal forest inventories over time.
- The data from this project has been archived at the ORNL DAAC, under the citation: Margolis, H., G. Sun, P.M. Montesano, and R.F. Nelson. 2015. NACP LiDAR-based Biomass Estimates, Boreal Forest Biome, North America, 2005-2006. Data set. Available online [http://daac/ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1273



Maps of (top) the distribution of above ground biomass (AGB) density ($Mg\cdot ha^{-1}$), (middle) two times the model-based standard error ($Mg\cdot ha^{-1}$), i.e. the ~95% confidence interval on the strata means, and (bottom) the relative error (%) of the AGB densities, i.e. (SE/mean) x 100. The maps were derived by assigning a mean AGB density class to each land cover class within an ecoregion based on the PALS-GLAS equations, which can be found in the paper as Table 2 (Alaska) and Table 4 (western and eastern Canada).



The locations where ground inventory plots were sampled from the aircraft using the portable airborne lidar system (PALS). The size of the circle indicates the number of ground plots sampled. The solid lines indicate the locations of the GLAS acquisitions 3c and 3f ground tracks that were sampled from the aircraft using PALS. Dark shading indicates the boreal forest.